

Has a fermiophobic Higgs boson been detected at the LHC?

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We show that, in the present inclusive searches for the Higgs boson at the LHC, a fermiophobic Higgs mimics the standard-model-like Higgs if its mass is around 125 GeV. For that mass the order-of-magnitude reduction of fermiophobic Higgs production cross sections is compensated by a corresponding increase in the Higgs branching fraction into $\gamma\gamma$, while the WW^* , ZZ^* , $Z\gamma$ signal yields are predicted to be somewhat smaller. The excess seen in the ATLAS and CMS fermiophobic Higgs boson searches in $\gamma\gamma$ channel, including the exclusive vector-boson-fusion analysis, suggests that the LHC sees a fermiophobic instead of a standard-model-like Higgs boson. If the Higgs boson turns out to be fermiophobic, many of our present ideas of new physics should be revised.

Motivation. Proving that the Higgs mechanism [1–4] is the origin of electroweak symmetry breaking is the main scientific aim of the Large Hardon Collider (LHC). Recently both the ATLAS and CMS experiments have published their combined results [5, 6] for searches for the standard model (SM) Higgs boson in data collected in 2011. The new combinations confirm the inconclusive evidence of a SM-like Higgs boson with mass $m_H \approx 125$ GeV. In both experiments the evidence originates predominantly from the excess in the $H \rightarrow \gamma\gamma$ channel [7, 8]. The CMS paper [8] also presents results for the exclusive vector boson fusion (VBF) analyses with forward-dijet tagging that unexpectedly gives an important contribution to the excess. ATLAS sees a not very significant excess in $H \rightarrow ZZ^* \rightarrow 4l$ for the same invariant mass [9], while the CMS data in this channel [10] as well as in $H \rightarrow WW^*$ [11] is, within errors, consistent with background. The fermionic channels $b\bar{b}$ and $\tau\bar{\tau}$ analyzed by the CMS [6] are not yet sensitive to the SM-like Higgs boson with the collected luminosity.

These results were updated in the Moriond 2012 conference where new results by ATLAS and CMS on searches for a fermiophobic (FP) Higgs boson in the $\gamma\gamma$ channel were presented. Both experiments observe consistently an excess of a 125 GeV FP Higgs boson with about 3σ local significance [12, 13]. If these hints will be confirmed, this would imply dramatic consequences on our understanding of electroweak symmetry breaking.

The possibility that (some) Higgses couple at tree level only to the gauge sector and not to fermions, the FP Higgs boson, is a well known logical option that can arise as a particular limiting case in models with an extended Higgs sector [14, 15]. However, more than by a particular theoretical model, the interest in the FP Higgs scenario was triggered by the new non-trivial Higgs phenomenology at LEP, Tevatron, SSC and LHC [16–23]. A consistent model for one FP Higgs boson as an effective low energy field theory of electroweak symmetry breaking was formulated only recently [24, 25]. In this framework the fermion masses, including the top quark mass, must come

from a different mechanism, *e.g.*, from technicolor.

In the context of quantum field theory, a pure FP Higgs boson with vanishing Yukawa couplings is not realistic. Whatever new physics mechanism is responsible for the fermion masses, at loop level non-vanishing Yukawa couplings are induced due to renormalization [24]. Although the size of induced Yukawa couplings depends on the new physics scale Λ , that can be considered as a theoretical uncertainty of the scenario, the generic prediction of the FP Higgs scenario is that the Higgs boson couplings to fermions are severely reduced. This is exactly what the combination of the CMS FP Higgs boson data indicates [26]. This implies, independently of the Higgs boson mass, that the Higgs production in gluon-gluon fusion $gg \rightarrow H$ (ggF), that is the dominant SM-like Higgs production process at the LHC, is negligible for the FP Higgs boson. The dominant FP Higgs production mechanisms at the LHC are VBF and associate production with vector bosons, VH , $V = W, Z$, that are at least an order of magnitude smaller than the SM production cross section $\sigma(gg \rightarrow H)$. At the same time, due to the suppressed decay $H \rightarrow b\bar{b}$, the FP Higgs boson branching ratios to the gauge bosons, $\gamma\gamma$, WW^* , ZZ^* and γZ are strongly enhanced for $m_H \lesssim 140$ GeV. As a result, the production cross section times branching ratio, $\sigma \times BR$, the quantity that is observable at the LHC, becomes strongly Higgs mass dependent for the FP Higgs boson. We note that in the case of a heavier FP Higgs, the high mass region is not yet ruled out by the LHC [27].

In this Letter we show that for the FP Higgs boson with mass around 124 GeV the inclusive production cross section in VBF plus VH channels times branching fraction into $\gamma\gamma$ is, within errors, equal to the SM Higgs boson $\sigma \times BR$ that is dominated by the ggF production. For the other channels, WW^* , ZZ^* , $Z\gamma$, we predict a moderate reduction of $\sigma \times BR$ for the FP Higgs. Consequently, the present inclusive LHC searches that reconstruct the Higgs invariant mass may accidentally support both the $m_H \approx 125$ GeV SM-like Higgs and the FP Higgs bosons because the fermionic channels $b\bar{b}$ and $\tau\bar{\tau}$ do not allow

to discriminate between the two scenarios yet. However, the CMS $H \rightarrow \gamma\gamma$ searches [8, 13] do include also the exclusive VBF channel with dijet tagging as one of the search categories, and the ATLAS inclusive search for FP Higgs [12] is optimized to diminish the ggF contribution. Because the signal exceeds expectations in those searches, the present LHC results support the possibility that the Higgs boson is fermiophobic.

The aim of this Letter is to emphasize that with a dedicated analysis optimized for the FP Higgs scenario the LHC experiments will be able to test this scenario already this year, possibly providing a first measurement of the new physics scale Λ connected to the fermion masses generation. In the VBF production, the transverse momenta of the forward jets coming from the scattered quarks balance the transverse momentum of the Higgs invariant mass system, that is larger than the typical Higgs momentum in the ggF process [28]. This helps also for the background suppression, as demonstrated in [12]. These factors allow the experiments to discriminate between the two dominant production mechanisms. The first LHC searches [12, 13] prove that the FP Higgs scenario can conclusively be tested with this year statistics surpassing the existing LEP [29–32], Tevatron [33] and the previous LHC bounds [34, 35]. Indeed, the LHC is much more sensitive to the FP Higgs scenario than to any other new physics scenario in which Higgs production is dominated by $gg \rightarrow H$, for example supersymmetry. To test supersymmetric Higgs production one could need to measure a few percent level deviations [36] from the SM prediction which may require years of running.

The importance of testing the FP Higgs scenario at the LHC goes far beyond ruling out or ruling in one particular new physics scenario. Clearly, if the FP Higgs is ruled out, this implies that $gg \rightarrow H$ is the main Higgs production mechanism as in the SM, and the Higgs Yukawa coupling to top quarks is indirectly measured. On the other hand, if the LHC experiments show that the presently preferred ≈ 125 GeV Higgs boson is fermiophobic, our current understanding of electroweak symmetry breaking and flavor physics must be revised. All models with fundamental Yukawa couplings, including the SM and the supersymmetric models, must be replaced with new mechanisms, *e.g.*, technicolor. One of the problems of the SM is a lack of dark matter that in the FP Higgs framework could be extra scalars that are stable due to matter parity [37]. If the Higgs VBF and VH production processes dominate, invisible FP Higgs boson decays [38–40] into dark matter scalars are enhanced at the LHC due to the increased branching fractions. This scenario may already have been hinted by the LHC WW^* data [41, 42].

A fermiophobic Higgs boson at the LHC. Here we present the inclusive FP Higgs boson production in the VBF, ZH and WH processes followed by decays into gauge bosons. To calculate the production cross sections

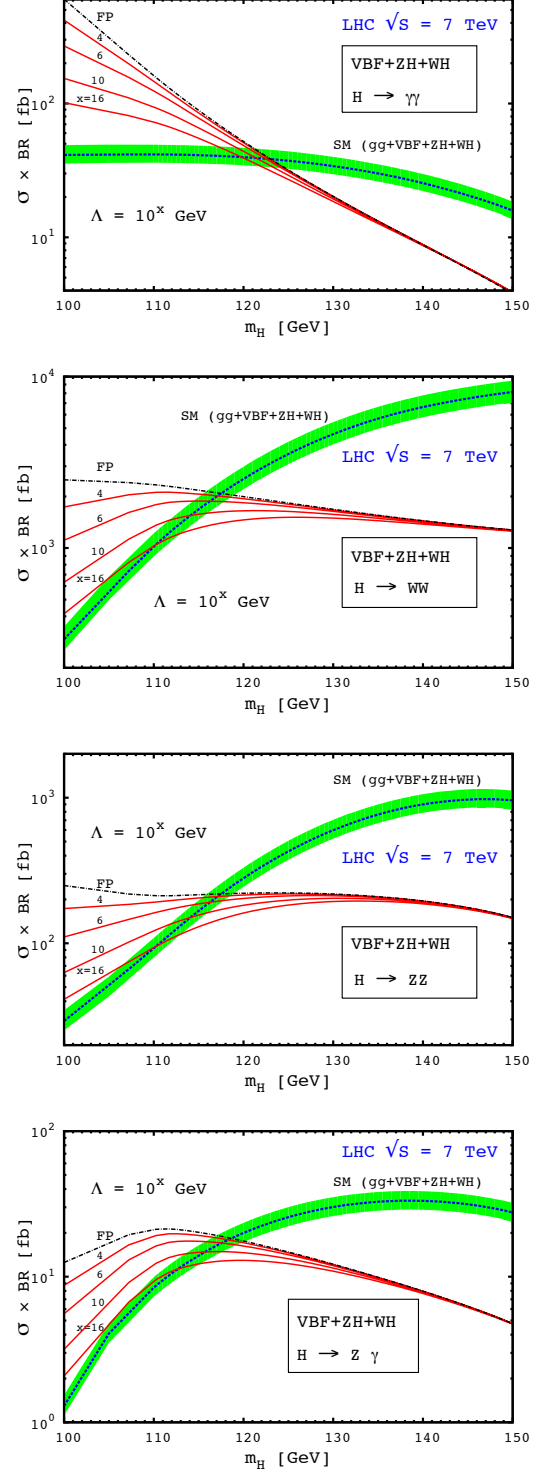


FIG. 1: Dependence of the inclusive cross-sections times branching fraction for the FP Higgs boson decays into $\gamma\gamma$, WW^* , ZZ^* and $Z\gamma$ (from up to down) on the Higgs mass m_H at 7 TeV LHC. Dash-dotted lines stand for the plain FP model, while red continuous lines represent the FP model with the inclusion of radiative corrections for several values of the new-physics scale $\Lambda = 10^{4,6,10,16}$ GeV. The dotted lines present the central values of the SM Higgs inclusive production, together with the theoretical error shown by the green band.

and branching fractions in the FP Higgs scenario we include the radiative corrections due to the SM fermion masses into our analyses following [24]. The radiative corrections depend logarithmically on the unknown new-physics scale Λ . We, therefore, treat this arbitrariness as a theoretical uncertainty on our predictions for $\sigma \times BR$ in the FP Higgs scenario.

As we discussed above, our aim is to compare the FP Higgs signal with the SM-like Higgs signal at the LHC. We, therefore, use the state-of-art estimation [43] of the inclusive SM Higgs production cross section in ggF, VFB and VH associate production channels to compare our results with the SM predictions. In Fig. 1 we present our results for $\sigma \times BR$ in the $\gamma\gamma$, WW^* and ZZ^* channels both for the FP Higgs boson and for the SM Higgs boson. Dash-dotted lines stand for the pure FP model. The red continuous lines indicate the FP model with the inclusion of radiative corrections for several values of the new-physics scale $\Lambda = 10^{4,6,10,16}$ GeV. The dotted line presents the central value of the SM Higgs inclusive production together with the theoretical error [43] presented by the green band. As seen in the upper panel of Fig. 1, the predictions for the FP Higgs model and for the SM Higgs in the $\gamma\gamma$ channel coincide if the Higgs boson mass is around 123 GeV. This value is close to the central value of the combined CMS Higgs signal. The ATLAS combined analyses prefers a somewhat higher Higgs boson mass, $m_H = 126$ GeV. Since the $\gamma\gamma$ channel dominates the excess in both experiments, we conclude, based on the discussion above, that the FP Higgs boson mimics the SM Higgs boson in the present searches. The two models can be discriminated by performing a dedicated search for the FP Higgs boson. The CMS exclusive VBF analyses in the $\gamma\gamma$ channel demonstrates that this goal is achievable.

Going beyond the $\gamma\gamma$ signal, we present in the lower panels of Fig. 1 our predictions for the FP Higgs $\sigma \times BR$ in the WW^* , ZZ^* and $Z\gamma$ channels. Those are predicted to be systematically lower than in the SM by a few tens of percent. This is one of our key predictions for the FP Higgs boson signal at the LHC that seems to be in qualitative agreement with the recently published combined Higgs boson results. Thus the present experimental data may support, although inconclusively, the FP Higgs production pattern over the SM.

Based on the ATLAS and CMS results, we focus on the Higgs boson mass region between 122 GeV and 126 GeV. We plot in Fig. 2 our predictions for $(\sigma \times BR)^{FP}/(\sigma \times BR)^{SM}$ for the different Higgs boson signatures assuming $m_H = 122, 124, 126$ GeV for two extreme values of the scale $\Lambda = m_H, 10^{16}$ GeV. The squares represent the central values of predictions, while the error-bars take into account the uncertainty in the SM cross sections. The theoretical uncertainties in the FP Higgs predictions due to the unknown new-physics scale are shown by the effect of the change in Λ . We can see that the $\gamma\gamma$ rates can be

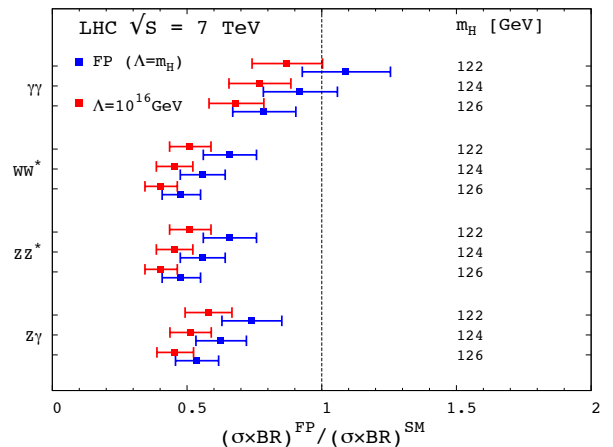


FIG. 2: Relative magnitudes of the FP Higgs prediction over a SM-like Higgs in different channels at the 7 TeV LHC for $m_H = 122, 124, 126$ GeV. The error bars correspond to the SM cross section uncertainties. The red (upper) and blue (lower) predictions show the theoretical errors associated with the new-physics scale Λ . For LHC at 8 TeV, the results are practically identical.

completely compatible with the SM ones. On the other hand, the other gauge boson channels show a depletion by a few tens of percents depending on the Higgs boson mass. We have checked that the ratios in Fig. 2 are practically identical for the 8 TeV LHC, since the dominant cross sections scale similarly with c.m. energy.

Although it is too early to draw statistically relevant conclusions, one can be tempted to compare our results in Fig. 2 with the CMS FP Higgs boson combination [26]. The latter reports a suppressed $H \rightarrow WW^*$ channel in VBF. In addition, the global fit indicates a somewhat suppressed FP Higgs production compared to the plain FP model predictions. The pattern observed by CMS could indeed be connected to a large Λ value.

Impact of the results on new physics scenarios. Dedicated searches for the FP Higgs boson at the LHC imply non-trivial results on fundamental physics independently of the outcome. If the FP Higgs boson will be ruled out by the LHC, the dominant Higgs production is determined to be ggF. This implies that the Higgs boson must have SM-like Yukawa couplings to the top quark that can indirectly be measured. Consequently, new physics scenarios like supersymmetry and multi-Higgs models will be favored.

If the Higgs boson turns out to be fermiophobic, it breaks the electroweak symmetry but does not give mass to quarks and leptons. In this case our standard views on electroweak symmetry breaking and on flavor physics must be revised. A particularly interesting question is what gives mass to the top quark. This would motivate studies of the top quark couplings at the LHC with the aim of finding unknown new physics that would be in-

volved in this sector.

If the Higgs boson is fermiophobic, studying Higgs invisible decays becomes easier at the LHC, due to the enhanced branching ratios, and may probe Higgs couplings to dark matter. Therefore direct discovery of dark matter particles at the LHC will require less statistics than in the case of the SM-like Higgs boson.

Conclusions. We have shown that the recently published inclusive ATLAS and CMS Higgs boson searches based on 2011 data do not discriminate between a SM-like Higgs boson and a FP Higgs boson. This is because for the Higgs boson mass presently favored by the LHC experiments, the Higgs production cross sections times branching fractions are accidentally similar in both scenarios. This happens despite of an order-of-magnitude difference in production cross sections and branching fractions in the two scenarios. At the 7 TeV LHC we predict similar Higgs signals in the $\gamma\gamma$ channel in both scenarios while the WW^* , ZZ^* and $Z\gamma$ channels are predicted to be somewhat suppressed in the FP Higgs scenario. Although not yet conclusively, the new ATLAS and CMS results support a FP Higgs boson with a new-physics scale Λ possibly close to the GUT scale. We urge the LHC experiments to perform a dedicated inclusive search for the FP Higgs boson in all channels that should be able to discriminate between the two scenarios with data to be collected this year. Ruling out or confirming the FP Higgs boson scenario will lay a path for future new physics searches at the LHC, giving information on the Higgs boson couplings to fermions, gauge bosons and possibly also to dark matter.

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